Utilization of Cavitation for Environmental Protection
- Killing Planktons and Dispersing Spilled Oil

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Abstract

This paper describes on the use of cavitation for environmental protection in the form of the following two subjects: killing plankton in water and dispersing spilled oil. The preliminary results showed that both uses are promising, which demonstrates the wide range of applications of cavitation utilization.

1. Introduction

The high concentration of energy at the collapsing stage of a cavitation bubble has detrimental effects, such as erosion, noise and vibration, on hydraulic machinery. However, we can use this effect for positive purposes, such as cutting and cleaning. (Kato (2000)) Moreover, this phenomenon can be used for environmental protection. Sato et al (1999) and Kalumuck and Chahine (2000) reported the possibility of cavitation usage to decompose chemicals in water.

The author started researches on the following two subjects.

1. Killing plankton in water using nozzle cavitation.
2. Dispersing spilled oil using a cavitating jet.

This paper describes preliminary results of the two research studies.

2. Killing plankton

An abnormal increase of plankton in lakes and ponds can destroy the ecological environment there. Another problem associated with plankton is the discharge of ballast water on oceangoing ships (IMO article (1998)). Sometimes the ballast water is discharged in the ocean thousands of miles away from where the ballast water was loaded. This means that the plankton in the ballast water travel this distance, and the newly introduced plankton may cause destruction of the ecological environment.

The author conducted a preliminary experiment to kill plankton in water taken from a pond at the Kawagoe campus of Toyo University, using a nozzle-type cavitation apparatus, the Nano-maker 200 by Nanomizer Co., Japan. Figure 1 shows a schematic chart of the Nano-maker 200.

The apparatus has a cavitation-generating cylinder with two nozzles whose diameters are 0.12mm (upstream) and 0.15mm (downstream), respectively, as shown in Fig. 2. The two nozzles are made from diamond to minimize wear. A hydraulic plunger generates a very high pressure up to 150MPa. The amount of discharge is 4ml per cycle. The pressure changes with time as a saw-tooth shape as shown in Fig. 3 because of the characteristics of the plunger movement. This apparatus was originally used to produce fine ceramic powder (Tokumitsu (2000)).

Combining one-dimensional continuous and momentum equations, cavitation numbers are estimated as 0.411 and 0.0023 at the upstream and downstream nozzles, respectively. Referring with Oba's experiment (1979) on the cavitation generation of a nozzle, we concluded that the cavitation should be generated at the both nozzles.

There were many types of plankton, such as chlorophyta, diatom, and ciliata in the water taken from the pond, as shown in Fig. 4. We examined the effect of cavitation by passing the pond water through the nozzles of the Nano-maker at two different maximum pressures: 150MPa and 100MPa. We also examined the effect of repeatedly passing the same water through the nozzles two or three times. Hereafter, we refer to these as 2 and 3 pass, respectively.

The cavitating flow through the nozzles destroyed the plankton completely because of the very high density of energy at the nozzles. Figure 5 shows micrographs taken after passing the water through the nozzles. The magnitude of enlargement was the same as that in Fig. 4. The planktons and other floating suspended particles were broken down into small pieces.

The effectiveness was also examined by the decrease in size of particles (planktons and solid particles) in the water. The 500ml of water was filtered by three filters of different pore sizes, 106μm, 20μm, and 0.7μm, successively. The minimum pore size of 0.7μm was chosen because all microorganisms were larger than this size. The amount of plankton and solid particles on a filter was weighed by an electronic precise balance (Shimadzu Co., AX-120), whose minimum reading was 0.1mg. Moisture in the air had a substantial effect on the measurement, and thus the filters were dried in an electric dryer and stored in an electric desiccator before and after the experiment.

The amount of plankton and solid particles on a filter was on the order of 1mg. Experimental conditions were 1 to 3 pass under two different maximum pressures, 100MPa and 150MPa. The amount of plankton and solid particles on the filter varied considerably in each different experiment even under the same conditions. Figures 6 and 7 are the averaged value of four runs under the same experimental conditions. The original pond water contains plankton and solid particles mainly larger than 20μm. The water after treatment (1 – 3 pass) contains more plankton and solid particles of 0.7-20μm and contains less plankton and particles larger than 20μm, when the maximum pressure is 150MPa (Fig. 6). The results at 100MPa (Fig. 7) show the same tendency, but are not as clear compared to those at 150MPa. We also notice that the repetition is not as effective by compared the results of 1 – 3 pass.

It is concluded that a cavitating nozzle is very effective at killing plankton in water. One pass at 150MPa is sufficient, but the optimal configuration of the apparatus and the effective usage were not fully examined in the experiment. They are a future task aiming for developing the practical applications of this method.

3. Dispersing spilled oil

Spilled crude oil from a tanker has a disastrous effect on the ocean environment. Mechanical recovery of oil is the most desirable countermeasure to protect the environment. However, the recovery sometimes becomes difficult for many reasons, such as bad weather. The dispersing of oil is the second-best solution in such a case and dispersants (chemicals) are used to accomplish this task. However, the dispersants may cause another problem because they are poisonous to some extent.

A cavitating jet is a promising candidate to disperse oil without side effects, because the dispersing effect of cavitation is well known, and it has been used for many practical purposes (Kato (2000)).

Figure 8 is the flowchart of the experimental apparatus. A high-pressure pump with three plungers (max. pressure: 5.6Mpa, max. flow rate: 18.9l/min) generated cavitating water jet flow at the nozzle outlet. The flow rate and pressure were controlled by valves and revolutions of the pump. Figure 9 shows the experimental setup. C-heavy oil was spread on the surface of fresh water in a small tank (L×B×D=312mm×394mm×478mm). The density and kinematic viscosity of the C-heavy oil are, respectively, 0.96g/cm^3 and 168cSt. A nozzle with a circular hole of 0.4mm was set at 45 degrees in the water. The cavitating jet from the nozzle hit a target plate, which was placed at the interface between the water and C-heavy oil. Cavitation bubbles collapsed at the target plate that dispersed the C-heavy oil.

The target plate was 32.5mm×58.3mm and 3mm thick, and placed vertically to the cavitating jet. The size of the target plate was chosen arbitrarily.

The standard experimental procedure was as follows.

(1) Five milliliters of C-heavy oil was introduced on the water surface of the tank. The oil was surrounded by a cylinder 100mm in diameter to prevent the oil from spreading out on the water surface.

(2) The standard exposure time to the cavitating jet was 30seconds.

(3) The water with dispersed oil was placed into a beaker. Then, approximately 0.4ml of the water with dispersed oil was put on a glass plate. The exact amount of the water was measured by weighing the glass plate with and without the water, using an electronic precise balance whose minimum reading was 0.1mg.

(4) The total number of dispersed oil droplets on the glass plate was measured by a microscope with 400 times magnification. The diameter of each oil droplet was also measured at the same time. Here, the dispersion rate of oil was defined as the ratio of the total volume of oil droplets with a diameter of less than 50μm to the initial oil volume of 5ml. Figure 10 is a typical microscopic picture of oil droplets.

Table 1 summarizes the experimental conditions and findings. We examined the effect of the target plate, the distance from the nozzle, and the relative position to the oil-water surface. We also changed the jet velocity and the exposure time, but kept constant the following conditions: the nozzle hole size (0.4mm), the nozzle angle (45degrees), and the amount of C-heavy oil (5ml).

We performed experiments three times for all conditions in order to obtain reliable data. Figure 11 shows the number distribution of dispersed oil droplets against the diameter. The size of the oil droplets is mostly less than 50μm in diameter, which is important because oil droplets less than 50μm in diameter do not remerge, and thus they are readily decomposed by bacteria in the ocean. The three experimental results are similar, which shows the reliability of the present experiment.

Figure 12 shows the effect of exposure time on the dispersion rate of oil. The dispersion rate accelerates with time. The cavitating jet flow induces circulation of the water with oil droplets inside the cylinder. Therefore, the number of oil droplets might increase in the region of cavitation bubble collapsing, which causes the increasing number of small droplets.

A careful examination of the dispersion rates in Table 1 shows that the best position of the target plate is 20mm from the nozzle outlet and at the interface between the oil and water. The effect of the target plate is obvious by comparing the results of Exp. No. 2 and 4. The dispersion rate increased almost three times by the target plate. Figure 13 shows the effect of cavitating jet velocity. The dispersion rate increases rapidly according to jet velocity. Such a tendency is often observed in experiments on cavitating flow.

It is concluded that the cavitating jet is a very promising method of dispersing spilled oil. A target plate is effective and the best configuration of the target plate was found in laboratory scale.

4. Concluding Remarks

Cavitation can be used for environmental protection in many different ways. The biggest advantage is that we use only pure water in the cavitation method. It gives images of safety and reliability to the people.

In the 20th century, cavitation was thought of as a detrimental phenomenon, which should be avoided. In the 21st century, cavitation will be a powerful tool for utilization, which can easily produce very high pressure, very high speed, and even very high temperature.

Acknowledgements

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Table 1. Experimental Conditions and Results of Oil-Dispersing Experiment

Exp. No.	Target Plate	Distance between Nozzle and Target Plate (mm)	Distance between Nozzle and Water Surface (mm)	Jet Velocity (m/s)	Exposure Time (sec)	Dispersion Rate (%)
1	Yes	10	10	53	30	1.9
2	Yes	20	20	53	30	5.6
3	Yes	30	30	53	30	0.7
4	No	---	20	53	30	1.9
5	Yes	20	10	53	30	1.1
6	Yes	20	20	53	10	0.5
7	Yes	20	20	53	20	0.7
8	Yes	20	20	41	30	1.6
9	Yes	20	20	46	30	1.9
10	Yes	30	20	53	30	0.7

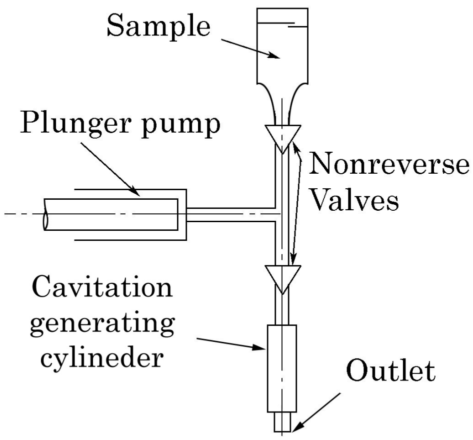

Figure 1 Nano-maker 200, nozzle type cavitation generator

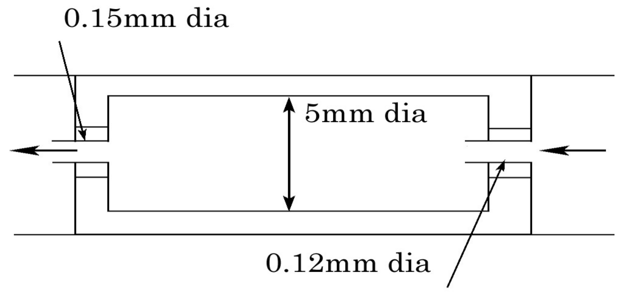

Figure 2 Cavitation-generating cylinder with two nozzles

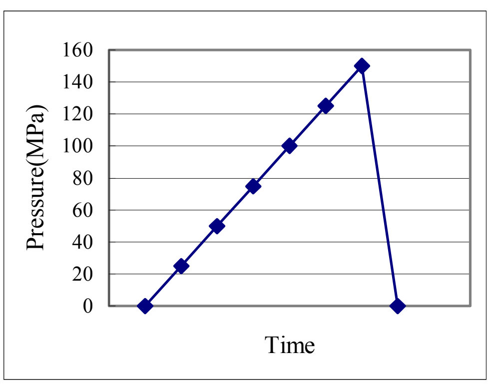

Figure 3 Pressure change in the cylinder with time

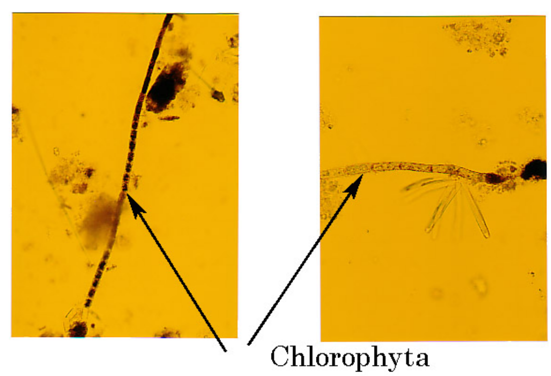

Figure 4 Micrographs of water in pond

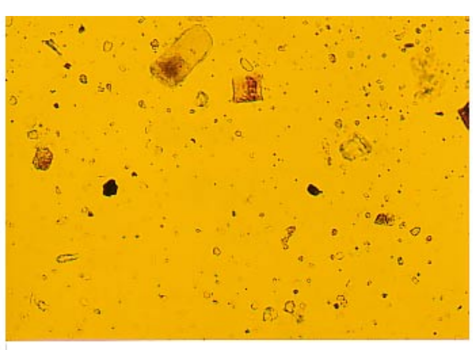

Figure 5 Micrograph after treatment

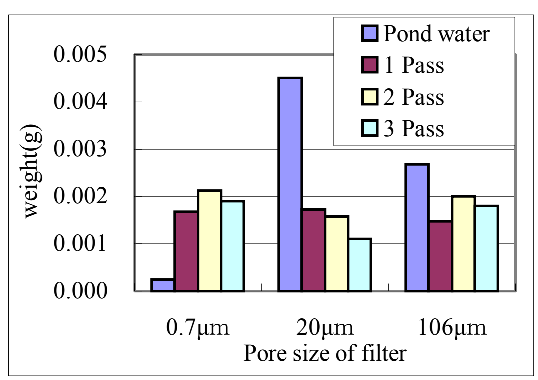

Figure 6 Size distribution of plankton and solid particles after treatment (150MPa)

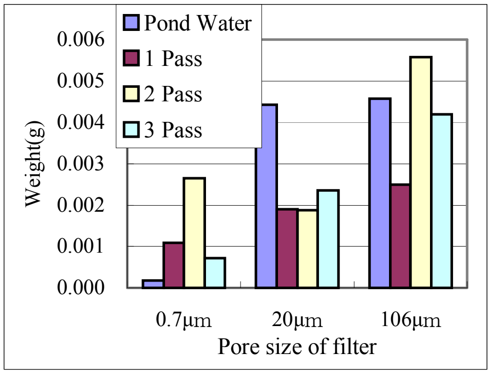

Figure 7 Size distribution of plankton and solid particles after treatment (100MPa)

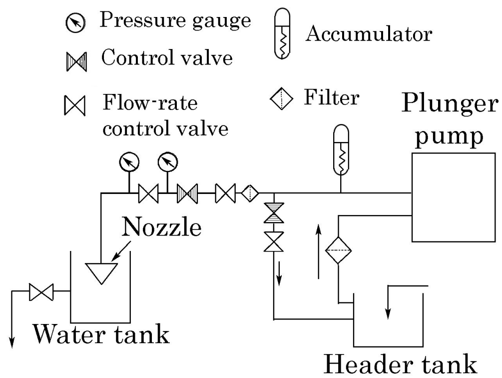

Figure 8 Flow chart of experimental apparatus for oil-dispersing experiment

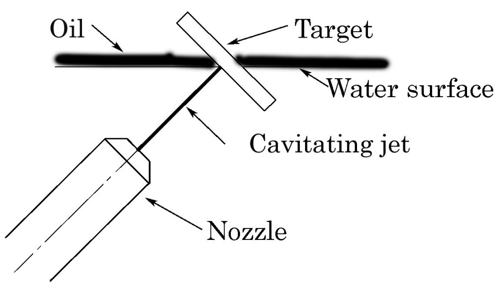

Figure 9 Experimental setup

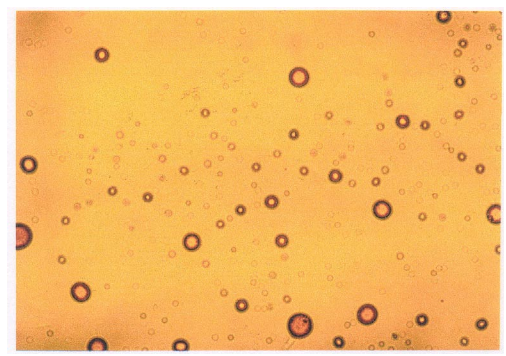

Figure 10 Typical micrograph of oil droplets in water (Exp. No. 2)

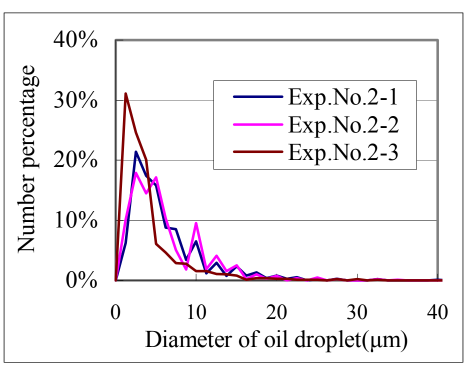

Figure 11 Number distribution of dispersed oil droplets against diameter

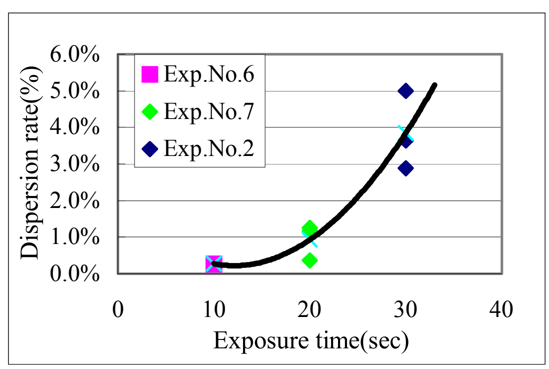

Figure 12 Effect of exposure time on oil dispersion

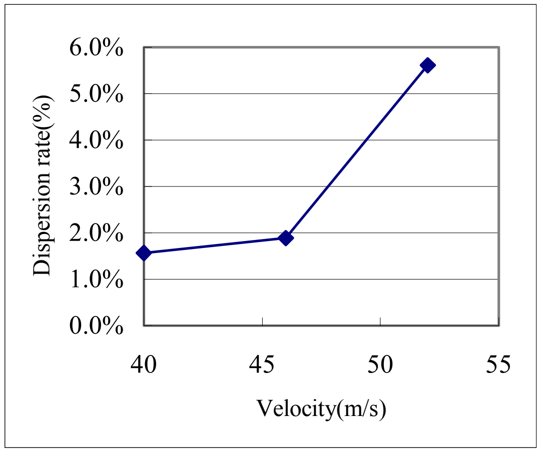

Figure 13 Effect of cavitating jet velocity on oil dispersion